J. Physiol. (1939) 96, 109–117 612.816:612.216.3

THE EFFECT OF FORCED BREATHING ON THE MOTOR CHRONAXIE

By B. DIJKSTRA and M. N. J. DIRKEN

From the Physiological Institute R.U., Groningen, Holland

(*Received* 12 *November* 1938)

The various papers on the influence of hyperventilation on the chronaxie [Bourguignon & Haldane, 1925; Bourguignon, 1931; Blumenfeldt & Köhler, 1929; v. Knorre, 1930; Johannes, 1933; Altenburger & Kroll, 1930*a*] dealing with experiments nearly exclusively on man, describe more or less completely the quantitative and time relations between the two without attempting an analysis of the phenomenon.

Such an attempt, however, seems to be justified not only by the importance ascribed to the chronaxie as an index to neuromuscular reactivity, but also by the extensive changes which appear to result from hyperventilation. We have investigated the conditions essential to the occurrence of the effect of forced breathing on the motor chronaxie and are reporting our results in the present paper.

Method

The experiments have been conducted on rabbits in urethane narcosis (1 g./kg. body weight). The motor chronaxie was measured either at the median nerve trunk or at the motor-point of the group of flexors innervated by this nerve (for localization see Banu [1922] and Reiners [1936]).

The chronaximeter used in our experiments was a variable condenser instrument of the ordinary type (source of current: City supply, 220 V. D.C.; variable condenser, 0·001–1 μF.; fixed condenser, 5 μF.). On its way to the animal the stimulating current passed through a resistance of 8300 Ω. and one of 6400 Ω., both the latter one and the animal being shunted by a resistance of 9000 Ω. All resistances used were without capacity and free from self-induction.

The large indifferent electrode (36 × 38 mm.) was strapped to the abdomen by a rubber band; in the experiments in which percutaneous stimulation was used, the smaller "active" cathode (diameter 6 mm.) was handled by the observer, who in order to minimize involuntary movements rested his forearm on a support fixed to the animal board. Both electrodes were of silver-plated copper and were applied to the skin which had been carefully depilated and was moistened with saline. In these experiments we did not use any kind of non-polarizable electrode, as we knew from experience that both in man and in animal the polarization at the surface of the electrodes is immaterial to the results of percutaneous stimulation. The determination of the rheobase was apt to give rather unstable results. This, however, may readily be ascribed to the difficulty experienced in keeping the cathode in exactly the required position, as the skin on the foreleg of the rabbit is but loosely connected to the underlying muscles. But the rheobase proved also to be influenced by the determination of the C_τ (i.e. threshold capacity for a current of double rheobasic strength), the latter being performed starting first from the smaller and then from the larger capacities. Stimulating afterwards with single rheobasic strength the threshold intensity of the current was commonly found to have shifted from the original value. As this often occurred more than once it is evident that some time was needed in order to get reliable results, although in general a complete determination could be accomplished in 3–4 min.

In the experiments undertaken in order to eliminate changes in skin impedance either a silver-silver chloride electrode was applied to the exposed trunk of the median nerve or a stout chloride-coated silver thread was pushed into the muscles of the foreleg through a slit in the skin.

We also tried to determine the accommodation factor of Hill [1936] but found this to be impracticable in rabbits by the constant appearance of galvanotonic contractions on stimulation with the strength of current needed. Sometimes these contractions even occurred on application of much lower voltages.

A most efficient way to hyperventilate narcotized rabbits proved to be the method described by Waud [1937] consisting of rhythmical stimulation of the phrenic nerves. On either side of the neck the nerve was freed from the underlying tissue over a distance of about 1·5 cm. and was laid on the electrode, which consisted of two fine platinum wires running across the inner wall of a small piece of rubber tube, the intact nerve being introduced through a longitudinal slit in the tubing.

As shown in Fig. 1 each phrenic nerve had its own stimulating circuit, the current being supplied by a transformer (*a*, *a*), its intensity and thereby the depth of the breathing being regulated by a potentiometer (*b*, *b*). A motor-driven mercury interruptor (*c*) was introduced in the primary circuit common to both transformers, and by its means it was possible to speed up the rate of breathing if desired up to 100 per min.

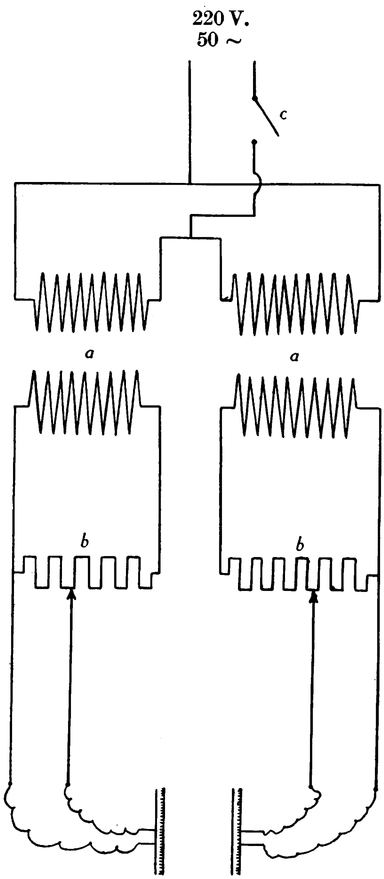

Fig. 1. Stimulating circuit for artificial respiration.

In all experiments the efficiency of the forced respiration was indirectly estimated by noting the duration of the resulting apnoea, but in a couple of cases the shift of the *p*H of the arterial blood during the hyperventilation has also been measured using glass electrodes and taking blood samples from the femoral artery at short intervals.

As is clearly shown by the data given in Table I, the method of forced inspiration adopted by us was quite efficient.

In each case the strength of the stimulus to the phrenic nerve was selected to produce a just about maximal contraction of the diaphragm. The first two rabbits (VI and VII) breathed through the normal air-paths, but as some trouble was experienced with the next animal (VIII), presumably caused by the soft tissues of the larynx being sucked in by the forced inspiration, in all following experiments the upper part of the air-way was eliminated either by tracheal cannula or by intubation. With this precaution one can always get a greatly increased ventilation of the lungs.

TABLE I

Rabbit	Before hyperventilation: Rate of normal breathing per min.	Before hyperventilation: pH arterial blood	During hyperventilation: Rate of forced breathing per min.	During hyperventilation: pH arterial blood	Apnoea sec.
VI	35	—	50	—	20
VII	34	7·45	38	7·60	35
VII	—	7·45	—	7·57	15
VII	—	7·41	—	7·57	25
VIII	38	—	58	—	72
IX	33	7·40	56	7·61	30
X	42	—	56	—	34
XI	36	—	83	—	25
XII	47	—	67	—	20

RESULTS

(a) *The effect of hyperventilation on the motor chronaxie*

The shift of the chronaxie determined by percutaneous stimulation at the motor-point of the toe flexors of the foreleg (τ m.p.) which results from forced breathing has been studied in about twenty rabbits.

In some experiments part of the electric current to the phrenic nerves must in some way or other have reached the adjacent brachial plexus as rhythmical contractions occurred in the muscles of the leg. But although in these cases it was impracticable to measure the chronaxie during the hyperventilation proper, these experiments were not useless, as the full effect of the forced breathing on the chronaxie persists for some time after the cessation of the hyperventilation.

An example of the effect produced is given in Fig. 2, while the greater part of our experimental results on this subject has been summarized in Table II.

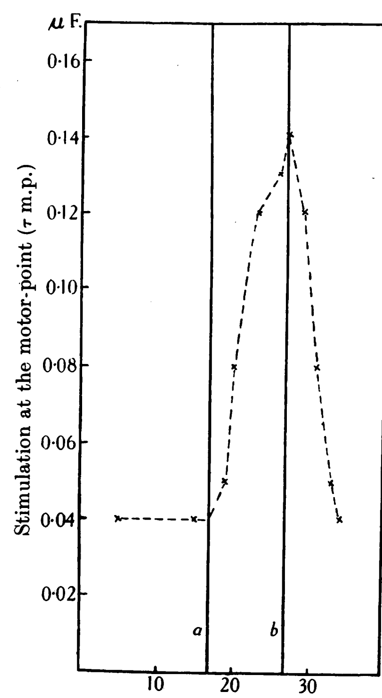

Fig. 2. Effect of hyperventilation on the motor chronaxie. Forced breathing from *a* to *b*.

It is obvious from these data that the forced ventilation of the lungs must have been fairly efficient, the mean duration of the apnoea being

TABLE II

Rabbit	Hyperventilation min.	Apnoea sec.	τ m.p. before hyperventilation μF.	τ m.p. during hyperventilation μF.	% increase
VII	10	39	0·04	0·11	175
VIII	10	28	0·03	0·10	233
IX	10	29	0·08	0·16	100
X	10	65	0·04	0·14	250
XI (left side)	10	56	0·03	0·12	300
XI (right side)	10	46	0·04	0·13	225
XII	16	35	0·08	—	—
XII	24	—	0·06	0·13	117
XII	8	22	0·05	0·14	180
XII	6	20	0·08	0·16	100
XIII	11	61	0·11	0·20	82
XIV	12·5	30	0·11	0·22	100
XV	10	34	0·03	0·16	433
XV	6	20	0·03	0·14	367
XVI	10	15	0·13	0·22	69
XVI	10	17	0·13	0·21	62
XVII	10	20	0·05	0·12	140
XVII	10	20	0·05	0·14	180
XVII	10	18	0·06	0·13	117

32 sec. (15–65 sec.). As it is not permissible for reasons mentioned above to attach any importance to the values found for the rheobasic intensity of the stimulus these are omitted from this as from the other tables in the present paper. The motor chronaxie, whose resting value shows marked individual variations, rises in all cases after the onset of the forced respiration, the mean increase being 180% of the original value.

The time taken to attain the maximum varied in different animals and also in different experiments on the same animal, but a period of 10 min. proved to be adequate as no further rise ever resulted from prolonged hyperventilation. At the end of the period of forced respiration the effect on the chronaxie persists for a couple of minutes (Fig. 2), after which it slowly disappears, the chronaxie returning to its resting value in about 7 min. We are unable to decide the question of the existence of a connexion between the intensity of the hyperventilation as estimated by the duration of the resulting apnoea and the height to which the chronaxie rises. The relation between the two varies within wide limits in the various animals and data on the same animal are too few in number to warrant any conclusion on this point.

The observations on the motor-point of the flexors have been supplemented by some on the trunk of the median nerve (τn), also by percutaneous stimulation. The results of these experiments, given in Table III, are sensibly the same as those of the previous series and we contented ourselves, therefore, in subsequent experiments with determinations at the motor-point only.

TABLE III

Rabbit	Hyperventilation min.	Apnoea sec.	τn before hyperventilation μF.	τn during hyperventilation μF.	% increase
XII	18	15	0·03	0·10	233
XII	18	25	0·03	0·10	233
XIV	10	30	0·02	0·05	150
XV	10	30	0·03	0·10	233

Summarizing the results of the above observations we may conclude that, as has already been found in man, the motor chronaxie of rabbits is strongly influenced by hyperventilation and shows a very distinct rise which persists for some minutes after the cessation of the forced respiration.

(b) *The effect of hyperventilation on the motor chronaxie after section of the nerve*

In sharp contrast to the rise which is a constant phenomenon under normal conditions, the motor chronaxie of the flexors remains completely uninfluenced by forced respiration after the section of the median nerve central to the point of stimulation as is demonstrated by the examples given in Table IV.

TABLE IV

Rabbit	Hyperventilation min.	Apnoea sec.	τ m.p. before hyperventilation μF.	τ m.p. during hyperventilation μF.
XII	11	20	0·02–0·03	0·02–0·03
XII	13	20	0·10	0·09–0·10
XIII	10	45	0·11	0·09–0·11

These results clearly show that the change in electric reactivity is under nervous control and is not caused by a change in the composition of the blood resulting from the forced breathing.

(c) *Sympathectomy and the effect of forced breathing on the motor chronaxie*

The results of nerve section raise the question whether the origin of the hyperventilation effect is to be sought in the spinal or in the autonomic nervous system. In order to decide this a series of experiments was undertaken in which the change of the chronaxie after forced breathing was studied on the same animal before and after stellectomy.

After comparing the reaction of the chronaxie to forced breathing at the motor-points of both forelegs the sympathetic trunk was removed on one side of the neck with inclusion of the stellate ganglion. After a couple of hours a second hyperventilation experiment was conducted in which the reaction on the operated side was compared with the unoperated side. The successful operation was not only evident from the resulting dilatation of the blood vessels of the leg but was verified every time after the death of the animal.

TABLE V

	Right side (intact)				Left side (sympathectomized)			
Rabbit	Hyperventilation min.	Apnoea sec.	τ m.p. rest μF.	τ m.p. hyperventilation μF.	Hyperventilation min.	Apnoea sec.	τ m.p. rest μF.	τ m.p. hyperventilation μF.
XVI	10	15	0·13	0·22	10	25	0·10	0·10–0·13
XVI	10	17	0·13	0·21	10	17	0·13	0·12–0·14
XVI	—	—	—	—	10	12	0·13	0·11–0·13
XVII	10	20	0·05	0·12	10	23	0·04	0·04–0·05
XVII	10	20	0·05	0·14	10	20	0·04	0·03–0·05
XVII	10	18	0·06	0·13	10	20	0·04	0·03–0·05

The meaning of the results of these experiments, some of which are reproduced in Table V, is quite evident. On the unoperated side the forced breathing produced the usual rise of the motor chronaxie. In the muscles of the other side, however, whose sympathetic innervation was destroyed, not a trace of the effect could be detected. Therefore the sympathetic innervation must be responsible for the rise of the chronaxie during hyperventilation.

(*d*) *Influence of the skin and underlying tissues*

Dr W. A. H. Rushton suggested to us that possibly the sympathetic fibres might be responsible for a change in skin impedance and thereby cause an apparent change in chronaxie. To decide this point we measured the chronaxie at the exposed trunk of the median nerve before and after a period of hyperventilation and complemented these observations with subcutaneous determination at the foreleg, the non-polarizable electrode being pushed into the muscle tissue.

The results summarized in Table VI do not leave any doubt. The rise of the chronaxie, which is a constant phenomenon with percutaneous stimulation, fails to appear both at the nerve trunk and at the muscle after removal of the skin and its underlying tissues.

TABLE VI

Exposed nerve trunk				Exposed muscles			
Hyperventilation min.	Apnoea sec.	τ rest μF.	τ hyperventilation μF.	Hyperventilation min.	Apnoea sec.	τ rest μF.	τ hyperventilation μF.
10	40	0·10	0·09	—	—	—	—
10	39	0·10	0·12	—	—	—	—
10	17	0·03	0·04	10	27	0·03	0·04
10	31	0·05	0·05	10	24	0·02	0·01
10	28	0·05	0·05	—	—	—	—
10	22	0·05	0·06	10	24	0·04	0·04
10	18	0·05	0·05	10	26	0·04	0·05

DISCUSSION

The results of the experiments cited above show that the rise of the chronaxie resulting from hyperventilation, first described by Bourguignon and Haldane, must be ascribed to a change in skin impedance, the physiological factors responsible for this change being under the influence of the autonomic nervous system. This example of the preponderating influence which the condition of the skin and the underlying tissues may exert compels caution in judging the results of chronaxie measurements by percutaneous stimulation. As many authors who have expressed the opinion that the neuromuscular excitability is influenced by the sympathetic system [Achelis, 1928, 1930 *a*, *b*, 1931; Foerster, Altenburger & Kroll, 1929; Altenburger & Kroll, 1930 *a*, *b*, 1931; v. Brücke, 1932] only made experiments on man and therefore only used percutaneous stimulation, their results have to be accepted with reserve.

Among these publications one of Altenburger & Kroll [1931] is of special interest. In a couple of patients, in which for therapeutical reasons the sympathetic trunk of the neck was unilaterally removed, these investigators found the effect of hyperventilation both on the motor and on the sensation chronaxie not only to be abolished but even to be reversed in as much as forced breathing caused a diminution of the chronaxie on the operated, and a rise on the unoperated side. Although we never observed a reversal of the effect of hyperventilation even when some 10 days had elapsed after the sympathectomy, our experiments confirm the results of these authors that the rise of the chronaxie depends upon the integrity of the sympathetic innervation.

Furthermore, it transpires from our experiments that the autonomic nervous system is readily influenced by hyperventilation and that the bodily changes resulting from this procedure are certainly not restricted to changes in the composition of the blood.

SUMMARY

Forced breathing produces in rabbits an increase of the motor chronaxie measured percutaneously both at the motor-point of the flexors and at the trunk of the median nerve.

This rise of chronaxie fails to appear after section of the median nerve and also after destruction of the sympathetic innervation.

Since the chronaxie remains uninfluenced by hyperventilation when measured at the exposed nerve trunk or the exposed muscles, it is concluded that forced breathing produces only an apparent change in chronaxie resulting from a changed impedance of the skin and the underlying tissues.

The skin impedance is controlled by the autonomic nervous system which in its turn is affected by the hyperventilation.

REFERENCES

Achelis, J. D. [1928]. *Pflüg. Arch. ges. Physiol.* **219**, 411.

Achelis, J. D. [1930 *a*]. *Pflüg. Arch. ges. Physiol.* **224**, 217.

Achelis, J. D. [1930 *b*]. *Pflüg. Arch. ges. Physiol.* **226**, 212.

Achelis, J. D. [1931]. *Z. ges. Neurol. Psychiat.* **60**, 536.

Altenburger, H. & Kroll, F. [1930 *a*]. *Z. ges. Neurol. Psychiat.* **123**, 733.

Altenburger, H. & Kroll, F. [1930 *b*]. *Z. ges. Neurol. Psychiat.* **124**, 527.

Altenburger, H. & Kroll, F. [1931]. *Z. ges. Neurol. Psychiat.* **135**, 501.

Banu, G. [1922]. Dissertation. *Faculté des Sciences. Recherches physiologiques sur le développement neuromusculaire chez l'homme et l'animal.* Imprimerie de la cour d'appel. Paris.

Blumenfeldt, E. & Köhler, H. [1929]. *Z. klin. Med.* **11**, 250.

Bourguignon, G. [1931]. *C.R. Soc. Biol., Paris,* **107**, 975.

Bourguignon, G. & Haldane, J. B. S. [1925]. *C.R. Acad. Sci., Paris,* **180**, 321.

Brücke, E. Th. v. [1932]. *Ergebn. Physiol.* **34**, 220.

Foerster, A., Altenburger, H. & Kroll, F. [1929]. *Z. ges. Neurol. Psychiat.* **121**, 581.

Hill, A. V. [1936]. *Proc. Roy. Soc.* B, **119**, 303.

Johannes, Th. [1933]. *Dtsch. Arch. klin. Med.* **174**, 83.

Knorre, H. v. [1930]. *Dtsch. Arch. klin. Med.* **168**, 1.

Reiners, H. [1936]. *Klin. Wschr.* **15**, 199.

Waud, R. A. [1937]. *Nature, Lond.,* **140**, 849.